A1 cont.

mixture of carbon nanotubes and oxygen-containing compounds of alkaline-earth metals. Typically, these oxygen-containing compounds of alkaline-earth metals are alkaline-earth triple oxide. Such an alkaline-earth triple oxide has been used as a coating on the cathode coils of fluorescent lamps to produce a stream of electrons in a thermionic process. The mixture of carbon nanotubes and alkaline-earth triple oxide may be coated on a filament of a metal or a metallic compound having a low work function to form a cathode of a gas discharge device. The composition of the present invention offers a comparable electron current at a lower cathode temperature; thus, helps to reduce the amount of energy expended in maintaining the cathode temperature. Furthermore, the resistance of carbon materials to sputtering in a high vacuum environment offers a reduction in the background gas pressure in gas discharge devices and an accompanying increase in luminous output. --

[Please amend paragraph 9 to read as follows:]

-- In another aspect of the present invention, a fluorescent lamp has a cathode the surface of which is deposited with a mixture of carbon nanotubes and an alkaline-earth triple oxide. The fluorescent lamp has a background pressure of less than about 0.3 kPa. --

[Please amend paragraph 10 to read as follows:]

-- In still another aspect of the present invention, a method for making a cathode of a gas discharge device comprises the steps of providing an amount of carbon nanotubes and an amount of oxygen-containing compounds of alkaline-earth metals in proportions such that an electron emission from the carbon nanotubes is substantial in relation to the total quantity of electrons emitted from the cathode; mixing the carbon nanotubes and the oxygen-containing compounds of alkaline-earth metals to form a mixture; providing an electrically conducting cathode structure; depositing the mixture on the cathode structure; and converting the oxygen-containing compounds of alkaline-earth metals to alkaline-earth metal oxides. --

[Please amend paragraph 11 to read as follows:]

-- In still another aspect of the present invention, particles of a metal catalyst are mixed and dispersed in the mixture of oxygen-containing compounds of alkaline-earth

G1 cont'd

metals before the mixture is applied on the cathode structure. The oxygen-containing compounds of alkaline-earth metals are then converted to alkaline-earth metal oxides. Carbon nanotubes are subsequently grown on the dispersed metal catalyst particles within the coating layer of the cathode structure. --

Please amend paragraph 14 to read as follows:

G2

-- The present invention provides a composition for cathodes of gas discharge devices, and more particularly, for fluorescent lamps. The composition of the present invention comprises a mixture of carbon nanotubes and oxygen-containing compound of alkaline-earth metals. Typically, the oxygen-containing compounds of alkaline-earth metals are alkaline-earth metal oxides. In a conventional fluorescent lamp, a stream of free electrons is liberated from the cathode, migrates to the anode, and ionizes a gas at a very low pressure in the process. The cathode is typically a coiled filament of a metal, such as tungsten, coated with a triple oxide of calcium, barium, and strontium that have low work functions. During operation of the fluorescent lamp, an amount of about two watts of electrical energy is supplied to the cathode material to heat it to a very high temperature, typically exceeding 1000 ^{0}C, to liberate the electrons from the coated filament. In the well-known mercury fluorescent lamp, a small amount of mercury is contained in the lamp to provide the discharge. In addition a background gas is necessary to reduce the required open circuit voltage for starting the discharge and to lessen the severity of a bombardment of the cathode by high-speed ions, which would damage and shorten the life of the cathode. A rare gas such as argon or a mixture of argon and krypton or neon is used as the background gas at a pressure of about 0.3-0.5 kPa. The Figure shows the luminous output of krypton-filled fluorescent lamps measured as lumens per watt ("lpw") as a function of krypton gas pressure. It is evident that the typical background pressure chosen to minimize the effect of damaging high-speed ions does not provide the optimum luminous output. Therefore, the lamp would be more energy-efficient if a cathode material could be used at a lower background gas pressure without being damaged. The composition of the present invention offers the promise of achieving this condition because of the resistance of carbon nanotubes to sputtering and evaporation at very high temperatures. Furthermore, it was estimated that the electric field at the tips of the carbon nanotubes could be intensified by a factor of at least 1000 because of the very small diameters of these nanotubes. Therefore, the composition of the present invention can provide an electron current comparable to that

generated from conventional triple oxide-coated cathodes at a lower temperature and a lower cathode fall due to a lower cathode potential. Cathode fall or cathode fall voltage is the potential difference between the arc stream and the cathode. Both a lower cathode temperature and a lower cathode fall contribute to increasing the energy efficiency of the gas discharge device. Moreover, a lower cathode temperature would increase the life of the cathode because of a lower evaporation rate of the triple oxide emission material. It is estimated that the rate of evaporation of the triple oxide emission material is reduced by about 50 percent for every decrease in the cathode temperature of about 30-50 ^{0}C. --

Please amend paragraph 17 to read as follows:

a3

-- A mixture of the present invention was made with 25 % (by volume) of carbon nanotubes and 75 % (by volume) of a conventional alkaline-earth triple carbonate. A small amount of a temporary binder, such as a resin or a starch, may be advantageously added into the mixture. The exact quantity of the temporary binder is not critical. The mixture was deposited by spraying on a coiled cathode of a conventional T8 fluorescent lamp (General Electric Company, Cleveland, Ohio) and the alkaline-earth carbonates were converted to alkaline-earth oxides in a non-oxidizing atmosphere as is well known in the art. The coiled cathodes having the coating layer of carbon nanotubes and alkaline-earth metal oxides were installed in conventional T8 fluorescent lamps. Twenty-four such lamps were produced for testing. In addition, twenty-three T8 fluorescent lamps also were made using the conventional alkaline-earth metal oxide emission mixture without carbon nanotubes for comparative testing. Cathode fall, cathode temperature, lamp voltage, and lamp current were measured for each fluorescent lamp. The result of the average and standard deviation for each of the measured parameters is shown below. --

Please amend paragraph 18 to read as follows:

a4

-- The cathode fall, cathode temperature and lamp voltage for the lamp of the present invention are lower than the corresponding parameters of the prior-art lamp, indicating that it is easier to liberate electrons from the cathodes of the lamps of the present invention. The twenty-degree reduction from the cathode temperature of the prior-art lamp is significant in prolonging the life of the cathode in view of the estimate that the evaporation

rate of the alkaline-earth emission mixture is reduced by about 50 percent for every 30-50 ^{0}C of cathode temperature. --

Please amend paragraph 19 to read as follows:

A4 cont

-- In another aspect of the present invention, the cathode coated with a mixture of carbon nanotubes and alkaline-earth triple oxide is installed in a fluorescent lamp. Carbon nanotubes provide a portion of the electrons required for generating and maintaining the discharge, thus lessening the requirement on the alkaline-earth triple oxide emission mixture. Therefore, the temperature of the cathode may be reduced and the life of the cathode may be extended. And since the carbon nanotubes can help to provide a comparable electron current at a lower open circuit voltage, the background gas pressure in the fluorescent lamp may be reduced to achieve a higher luminous output. Background gas pressure may be advantageously reduced to about 0.1-0.2 kPa according to the Figure to achieve an optimum luminous output in a krypton-filled fluorescent lamp. Similarly, the background gas pressure may be reduced for lamps filled with other rare gases. --

Please amend paragraph 20 to read as follows:

-- A cathode of the present invention for a gas discharge device may be made by a process comprising the step of (1) providing an amount of carbon nanotubes and an amount of oxygen-containing compounds of alkaline-earth metals in proportions such that an electron emission from the carbon nanotubes is a substantial portion; such as at least 10 percent, preferably at least 20 percent, more preferably at least 50 percent, and most preferably at least 80 percent; of the total number of electrons emitted from the cathode; (2) mixing the carbon nanotubes and the oxygen-containing compounds of alkaline-earth metals to form a mixture; (3) providing an electrically conducting cathode structure such as a sleeve, a stick, a coil, a coiled coil, or a triple coil; (4) depositing the mixture on the cathode structure; and (5) converting the oxygen-containing compounds of alkaline-earth metals to alkaline-earth metal oxides to form a finished coating layer comprising carbon nanotubes and alkaline-earth metal oxides. The oxygen-containing compounds of alkaline-earth metals may be selected from the group consisting of carbonates, nitrates, oxalates, citrates, and acetates. The proportion of carbon nanotubes in the finished coating layer may be from about 0.1 percent by volume to about 95 percent by volume, preferably from

about 5 percent by volume to about 90 percent by volume, more preferably from about 20 percent by volume to about 90 percent by volume, and most preferably from about 30 percent by volume to about 90 percent by volume. The deposition of the mixture of carbon nanotubes and oxygen-containing compounds of alkaline-earth metals on the cathode structure may be carried out by painting, dipping, spraying, or electrophoresis. The conversion of oxygen-containing compounds of alkaline-earth metals to alkaline-earth metal oxides is preferably done in a non-oxidizing atmosphere at a temperature and for a time sufficient to substantially complete the conversion. Typically, a temperature in the range from about 1000 ^{0}C to about 1700 ^{0}C is sufficient for this conversion. More typically, the temperature is in the range from about 1200 ^{0}C to about 1500 ^{0}C. --

Ok ent.

Please amend paragraph 21 to read as follows:

-- In another aspect of the present invention, the oxygen-containing compounds of the alkaline-earth metals are mixed with particles of a metal catalyst to form a mixture. A small amount of a temporary binder, such as an epoxy resin or a starch, may be added in the mixture to help its adherence to the cathode structure. Such a temporary binder is typically decomposed or burnt off during a subsequent firing of the coated cathode. The mixture is deposited on the cathode structure by painting, dipping, spraying, or electrophoresis. The coated cathode is then fired in a non-oxidizing atmosphere to convert the oxygen-containing compounds of alkaline-earth metals to alkaline-earth metal oxides. Carbon nanotubes are then formed on the catalyst particles dispersed within the layer of alkaline-earth metal oxides by any cracking and pyrolyzing process mentioned above. The finished cathodes are installed in gas discharge devices by any well-known method to provide an increase in efficiency thereto. --

In the Claims:

Please cancel claims 26-38 without prejudice or disclaimer pursuant to an election to prosecute claims 1-25 made on September 2, 2002. Applicants will file one or more divisional patent applications to claim the subject matter of claims 26-38 at an appropriate future time.

Please amend claims 1, 2, 4-7, 12, 13, and 15-18 to read as follows: